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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

MAGNITUDE AND FREQUENCY OF FLOODS FROM DRAINAGE AREAS LESS THAN 100 SQUARE MILES IN MONTANA

By F. C. Boner and R. J. Omang

Prepared in cooperation with the
Montana State Highway Commission
and the U. S. Bureau of Public Roads

Open-file report
Helena, Montana
1967

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CONTENTS

Page

Abstract 1

Introduction 2

Description of the State 4

  Topography 4

  Drainage 5

  Climate 5

Flood-frequency relations 7

  Method of analysis 7

  Records used 8

  Flood frequency at a gaging station 8

    Types of flood series 8

    Flood-frequency curves 9

  Statewide flood-frequency relations 10

    Magnitude of the 10-year flood 10

    Magnitude of the 25-year flood 12

Application of flood-frequency relations 12

Limitations 13

References cited 16

ILLUSTRATIONS

Page

Figure 1. Map showing flood-frequency regions in Montana 17

2. Map showing distribution of average annual runoff in Montana 18

3-6. Graph showing relation of 10-year flood to drainage area and average annual runoff:

3. Region A. 19

4. Region C. 20

5. Region D. 21

6. Regions E and F 22

7. Graph showing relation of 10-year flood to drainage area in regions B, G, H, I, J, K, L, and M. 23

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By F. C. Boner and R. J. Omang

ABSTRACT

A method is presented for determining the magnitude of floods with 10- and 25-year recurrence intervals from drainage areas of less than 100 square miles in Montana. Curves express the relation of the 10-year flood to basin characteristics. In most of the mountainous areas of Montana, size of drainage basin and average annual runoff were found to be important factors in determining the magnitude of the 10-year flood. Only size of drainage basin was used as an independent variable in the remainder of the State.

Ratios between the 25-year flood and the 10-year flood are given for each of 13 regions so that the 25-year flood can be obtained by multiplying the 10-year flood by the appropriate ratio. The relations are based on 5 or more years of record at gaging stations on streams that are virtually unregulated.

INTRODUCTION

Knowledge of the magnitude and frequency of floods is necessary for proper design of a culvert or other hydraulic structure. The selection of a "design flood" introduces an element of risk that should be consistent with the economics and policies required in the design. When a "design flood" is too small, the element of risk is too great, and frequent floods greater than the "design flood" may cause frequent malfunction or even failure of a hydraulic structure. Thus, a low initial cost will quickly be overcome by a continuing high cost of repair or replacement. When a "design flood" is too great, the element of risk is too small, and the probability of malfunction or failure also becomes very small; however, the assurance of trouble-free operation incurs a high first cost. For both extreme conditions, the long-term cost of the hydraulic structure may be excessive.

The purpose of this report is twofold: (1) To present a method for estimating the magnitude of floods with 10- and 25-year recurrence intervals on any unregulated stream in Montana that has a drainage area smaller than 100 square miles and (2) to evaluate the adequacy of the peak discharge data collected by the crest-stage stream-gaging program. The results obtained by the methods to be described may differ somewhat from those obtained by the methods described by Patterson

(1966) and Bodhaine and Thomas (1964) for drainage areas of 100 square miles or less.

The effect of size and altitude of the drainage basin, channel slope, and average annual runoff on the 10-year flood peaks was investigated. The size of drainage basin was found to be the most important variable affecting the 10-year flood. Average annual runoff was found to be a significant variable in relation to the 10-year flood within most of the mountainous areas of Montana. The other variables investigated had no significant relation to the 10-year flood.

This report was prepared as a part of a cooperative program with the Montana State Highway Commission and the U. S. Bureau of Public Roads for investigating peak discharges from small drainage basins in Montana. It was prepared in the Helena office of the U. S. Geological Survey under the direction of Charles W. Lane, district chief, Water Resources Division. Technical guidance was provided by H. C. Riggs, Chief, Hydrologic Studies Section, Surface Water Branch, Water Resources Division, U. S. Geological Survey. Credit is given to J. L. Patterson of the Little Rock, Ark., office of the U. S. Geological Survey for use of peak discharge tabulations and station flood-frequency curves for gaging stations in the Missouri River basin in Montana.

Peak-discharge data collected through the cooperative program were supplemented by streamflow data collected by the U. S. Geological Survey in cooperation with many Federal and State agencies. Credit has been given for this cooperation in the annual series of water-supply papers of the Geological Survey entitled "Surface Water Supply of the United States", and since 1960, in the annual Geological Survey surface-water reports for Montana.

DESCRIPTION OF THE STATE

Topography

The State of Montana is divided into the Northern and Middle Rocky Mountain and Great Plains physiographic provinces. About the eastern three-fourths is in the Great Plains; the western part is an area of mountains and intermontane valleys. Many peaks in the Rocky Mountains exceed 10,000 feet in altitude. The streams west of the Continental Divide in Montana have cut to lower altitudes than those east of the divide. The lowest point in Montana is about 1,800 feet above sea level where the Kootenai River enters Idaho. The plains area slopes generally eastward from about 4,000 feet near the mountains to 2,000 to 3,000 feet at the east edge of the State, but the slope is interrupted by basins and ranges of hills and mountains of structural origin. A more detailed description of the physiographic divisions is given by Fenneman (1931).

Drainage

The area east of the Continental Divide drains almost entirely into the main stem of the Missouri River or its principle tributary, the Yellowstone River; a small area between Hudson Bay Divide and the Continental Divide is drained by the St. Mary River to Hudson Bay through the Saskatchewan River in Canada. The western part is drained by tributaries of the Columbia. The Kootenai River enters Montana from Canada and flows into Idaho. The Clark Fork receives the Flathead River from Canada and numerous tributaries from Montana and then flows into Idaho.

There are a few small closed basins near the Canadian border east of the Continental Divide and also a few in the area northwest of Billings.

Climate

The climate of Montana is controlled by factors such as the location of the State on the continent, a barrier effect from high mountains in the western part of the State, altitude, latitude, and the general movement of air masses. West of the Continental Divide the climate is of the northern Pacific Coast type, while east of the Divide it is of the Great Plains type.

Montana has relatively high temperatures during the summer and low temperatures in the winter. The average temperature for July is about 68°F ranging from an average of 65° in the west to 72° in the southeast. The average January temperature is about 19°F ranging from 10° in the northeast to 22° in the south central.

Precipitation ranges widely in Montana and depends largely upon topographic influences. The mountain ranges and the areas adjacent to mountain ranges, in general, are the wettest, although there are a few exceptions where the "rain shadow" effect appears. The western part of the State is the wettest and the south-central part near the Wyoming boundary is the driest. A few valleys in the west, such as the Deer Lodge and Little Bitterroot, are relatively dry. Annual precipitation ranges from less than 10 inches near Helena to more than 100 inches at Grinnell Glacier in Glacier National Park.

Annual snowfall ranges from quite heavy (up to 300 inches) in some parts of the mountains in the western half of the State to about 20 inches in parts of northern Montana east of the Continental Divide. Most snow falls during the November-March period, but heavy snowstorms can occur as early as mid-September or as late as May 1 in the higher parts of the southwestern half of the State. In eastern Montana early or late season snows are not common.

The greatest volume of flow of Montana's rivers occurs during the spring and early summer months with the melting of the winter snowpack. Heavy rains falling during the spring thaw constitute a serious flood threat. Flash floods, although restricted in scope, are probably the most numerous and result from locally heavy rainstorms in the spring and summer. One of the most damaging floods in recent years occurred in 1964. Other significant floods occurred in 1948, 1952, and 1953.

FLOOD-FREQUENCY RELATIONS

Method of Analysis

The methods of computing flood-frequency relations used in this report were developed by engineers of the Geological Survey. Some are from Dalrymple (1960). In addition, several hydrologic factors suggested by Benson (1962, 1964) were investigated to see if they improved the flood-frequency relations.

Briefly, records of annual peak discharges were used to relate a selected index flood to certain significant characteristics of drainage basins. The three major steps used were:

(1) Definition of flood-frequency relations for a specific stream-gaging station.

(2) Multiple-correlation analysis to determine flood frequency relations for any stream of less than 100 square miles of drainage area in Montana.

(3) Statistical comparison between floods having recurrence intervals of 10 and 25 years.

Records Used

Peak-flow records 5 or more years in length from 160 continuous-record gaging stations and 123 crest-stage partial-record gaging stations in Montana, not appreciably affected by regulation or diversion, were used in the analysis. Stations having more than 10 years of record were used to define the 10- and 25-year flood relations.

Flood Frequency at a Gaging Station

Types of Flood Series

Flood-frequency data at a gaging station can be analyzed either as an annual flood series or as a partial-duration flood series. In the annual series, only the highest peak discharge during each water year (Oct. 1 to Sept. 30) is used. The partial-duration flood series is a list of all flood peaks that exceed a selected base discharge regardless of the number of peaks during the year. Although the annual flood series does not take into consideration some high floods that are not the highest for the year, it has the advantage of being a complete duration series and is adaptable to mathematical analysis. Practically the same results will be obtained by use of either series for recurrence intervals greater than 10 years.

Peak discharge records obtained at crest-stage partial-record gaging stations are not adequate for determination of peaks above a selected base because frequently records of all the floods are not obtained. The annual flood series has been used for analysis in this report.

The recurrence interval of a flood in the annual flood series is the average interval of time within which a given flood will be equaled or exceeded once as an annual maximum. From the definition given for recurrence interval in the annual flood series, the probability of occurrence of a flood of a selected magnitude during a given year is the inverse of the recurrence interval. Thus, a 10-year flood has a 10-percent chance of occurring in any year, and a 25-year flood has a 4-percent chance of occurring in any year. It should be emphasized that there is no implication that a 10-year flood will occur once every 10 years or that one 25-year flood will occur once every 25 years.

Flood-Frequency Curves

A flood-frequency curve shows the relation between the peak discharge and the recurrence interval. Annual peak discharges for each station were plotted at the computed recurrence interval on a special form (Powell, 1943) developed for use in the analysis of flood frequencies by the theory of extreme values (Gumbel, 1941). Recurrence interval was computed by the formula $T = (n + 1)/m$, where T is the recurrence interval in years, n is the number of years of record, and m is the order number, beginning with the largest flood as number 1. For a record augmented by knowledge of one or more historical floods, n is the number of years during which the relative order of magnitude of the flood is known. Recurrence intervals for all annual peaks at each gaging station were computed and plotted against the corresponding discharge. A smooth curve was fitted to the plotted points by visual inspection. The discharge corresponding to the 10- and 25-year (when available) recurrence interval was selected from the curve for use in the regional analysis. This method gives less weight to extreme values with indicated recurrence intervals that may not be representative of the long-term average.

Statewide Flood-Frequency Relations

Magnitude of the 10-Year Flood

The 10-year flood was used as the index flood in this analysis; it is defined as the discharge that has a 10-year recurrence interval. The magnitude of the 10-year flood is a measure of certain physiographic and climatologic characteristics of the drainage basin. It was estimated for each station graphically from the individual frequency curves.

The factors that were considered to determine the relation of the 10-year flood to the basin characteristics were: size of drainage basin, altitude of the drainage basin, channel slope, and average annual runoff. Many other factors probably influence the magnitude of the 10-year flood but they are difficult to evaluate.

Multiple-correlation analysis of the 10-year flood to measurable basin characteristics indicates that Montana can be divided into 13 regions, designated by letters A through M in figure 1. Divisions between regions were determined by trial and error groupings of stations where the 10-year flood correlated reasonably well with size of drainage basin; however, the exact boundaries between regions were usually based on topographic features such as drainage divides.

In addition to size of drainage basin, the use of average annual runoff (Busby, 1966) significantly improved the correlations in five of the regions. Figure 2 is a map showing the distribution of average annual runoff for the State.

Curves of relation between the 10-year flood, drainage area, and average annual runoff (where applicable) are shown in figures 3-7.

Magnitude of the 25-Year Flood

Following the multiple correlation where the 10-year flood was used to define the 13 flood-frequency regions, ratios of the 25-year flood to the 10-year flood were computed for stations that had a long enough record to adequately define the 25-year flood. It is assumed that the ratios of the 25-year flood to the 10-year flood for stations having a long period of record are similar to those for the stations having a short record. Median values of the ratios computed for the regions are shown in the following table.

Ratios of the 25-year flood to the 10-year flood

Region	Median ratio	Region	Median ratio
A	1.3	G	1.4
B	1.2	H	1.25
C	1.3	I	1.25
D	1.25	J	1.2
E	1.25	K	1.45
F	1.5	L	1.45
		M	1.45

APPLICATION OF FLOOD-FREQUENCY RELATIONS

The general procedure for determining the magnitude of floods having a 10- and 25-year recurrence interval at any site in Montana with a drainage area of less than 100 square miles is:

1. Determine the size of the contributing drainage

area. For most basins, contributing drainage area is equivalent to total drainage area. For some, the contributing drainage area is less because surface runoff is retained on flat tableland, depressions, or closed basins. Contributing drainage area can be measured on topographic maps or aerial photographs after outlining the area encompassing a continuous stream pattern.

2. Determine from figure 1 the flood-frequency region (A-M) in which the site is located.

3. For regions A, C, D, E, and F, determine the average annual runoff of the basin from figure 2.

4. Determine the 10-year flood from the appropriate hydrologic region curve (figs. 3-7). For regions A, C, D, E, and F, the 10-year flood must be obtained by interpolating between curves.

5. Multiply the 10-year flood (step 4) by the ratio of the 25-year flood to the 10-year flood (page 12) for the appropriate region to obtain the 25-year flood.

LIMITATIONS

The dependability of the results of this analysis is limited tc a large extent by the amount of streamflow data presently available. Prior to the start of peak-discharge data collection on small drainage basins using crest-stage partial-record gaging stations, there was a Statewide deficiency of peak-discharge data for drainage basins less than 100 square miles. Peak-discharge data from the partial-record stations available for this analysis were used to define the flood-frequency relations for the small drainage basins. However, only floods for recurrence intervals of 10 years or less could be defined from the records of such short length. Reliability of the 10-year flood defined by the short period of record available is only fair. More peak-flow data are needed at the partial-record gaging stations to improve the definition of the 10-year flood. Reliability of the 25-year flood determined using methods given in this report is poor owing to the assumption that the ratios of the 25-year flood to the 10-year flood for stations having a long period of record were similar to those for stations with a short record. Until more data are collected at the stations having short periods of record, reliability of this assumption will not be known.

All curves shown in this report have been drawn to the limits warranted by the data. Extension of the curves beyond the limits shown is not recommended.

This report can be used only for determining the magnitude of the 10- and 25-year floods on any unregulated stream for drainage areas of less than 100 square miles. The magnitude and frequency of expected floods of any recurrence interval between 1.1 and 50 years for drainage areas of more than 100 square miles can be determined by methods outlined in Water-Supply Paper 1679 (Patterson, 1966) for streams in the Missouri River basin part of Montana, and Water-Supply Paper 1687 (Bodhaine and Thomas, 1964) for streams in the upper Columbia River basin part of Montana. Similar information will be available in the near future in Water-Supply Paper 1678 for the Hudson Bay drainage part of Montana.

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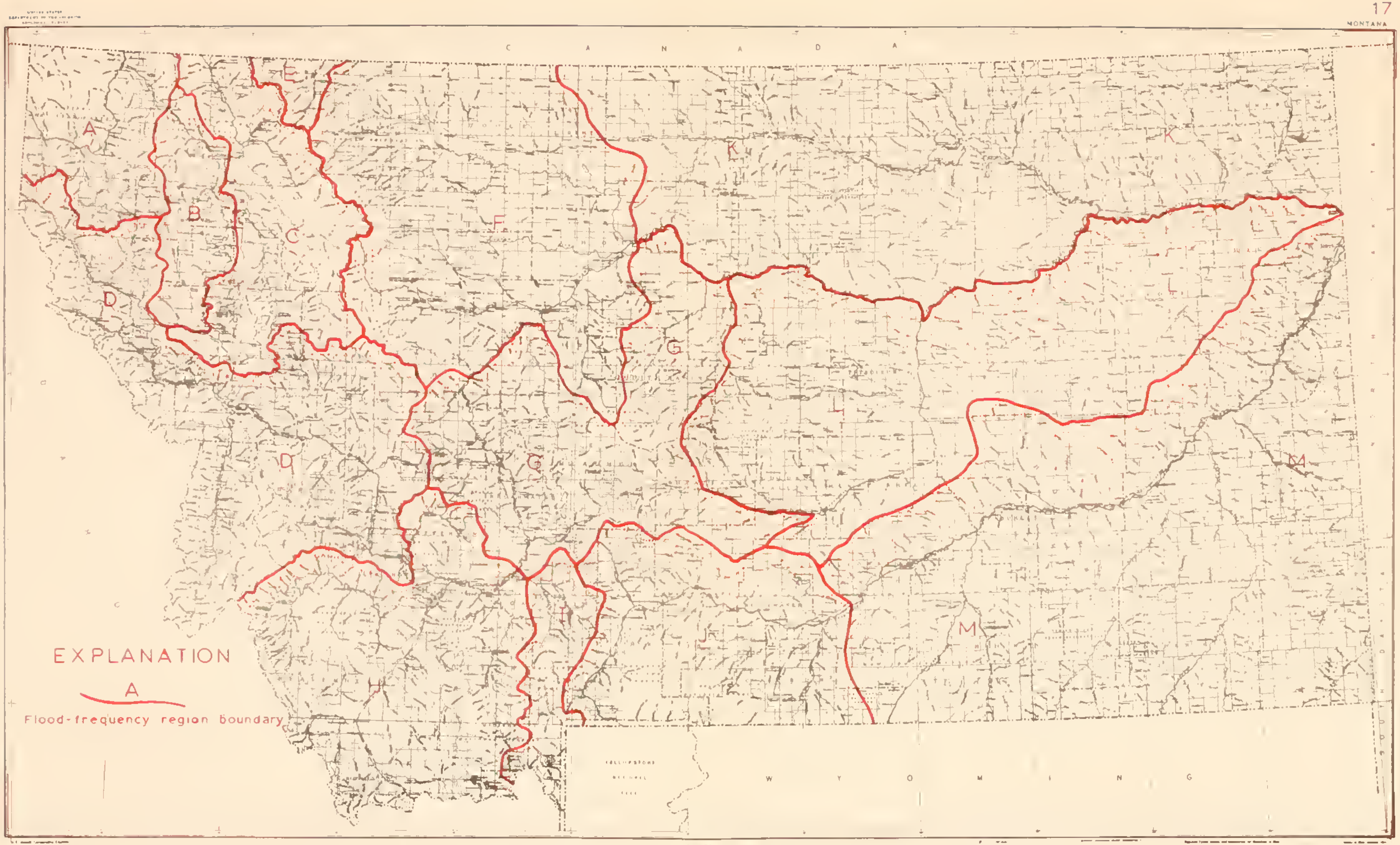
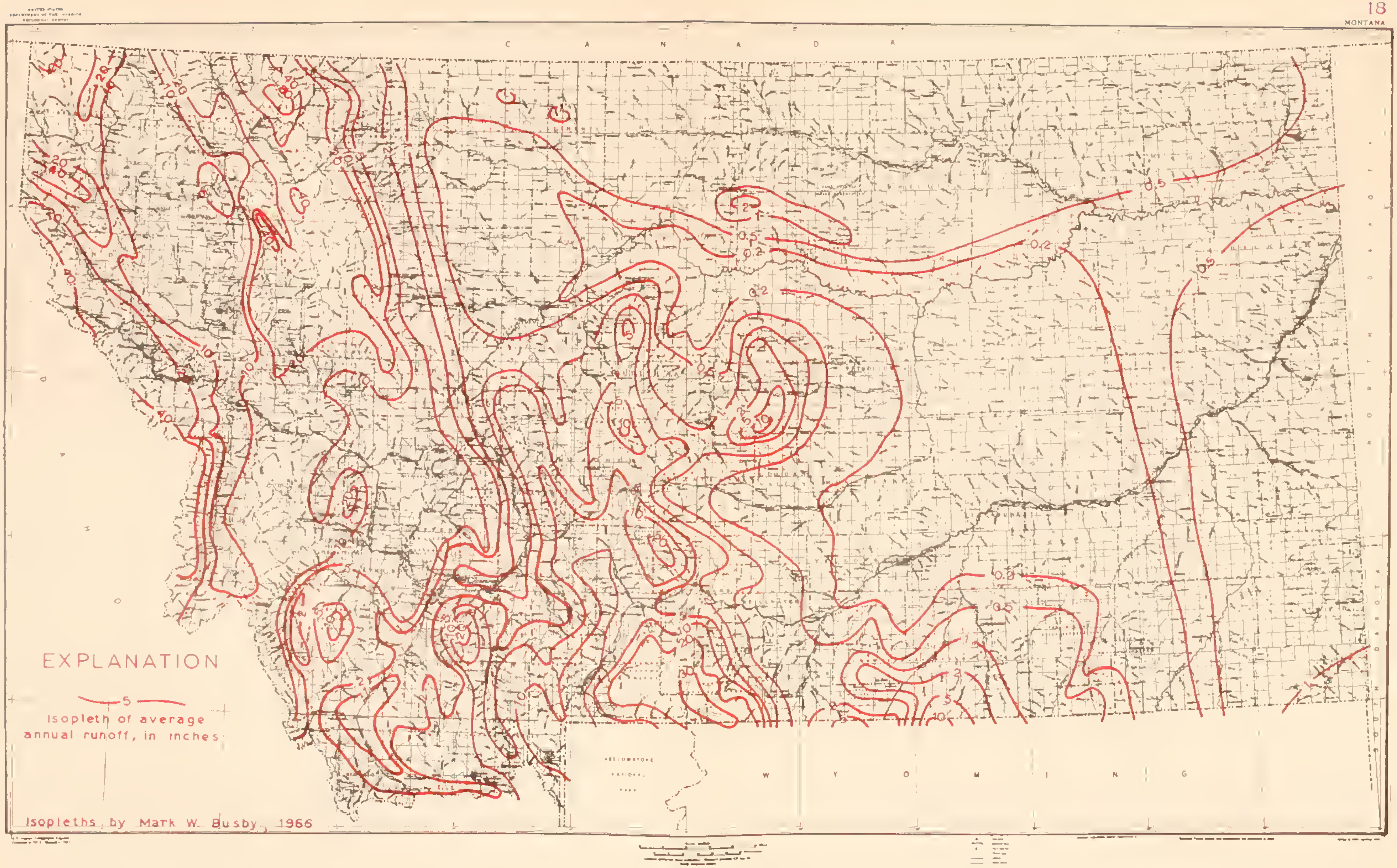


FIGURE 1 - FLOOD-FREQUENCY REGIONS IN MONTANA.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IDAHO
EXPLANATION
5
Isopleth of average annual runoff, in inches
Isopleths by Mark W. Busby, 1966
0.2
0.5
1
2
5
10
20
30
40

FIGURE 2 - DISTRIBUTION OF AVERAGE ANNUAL RUNOFF IN MONTANA.

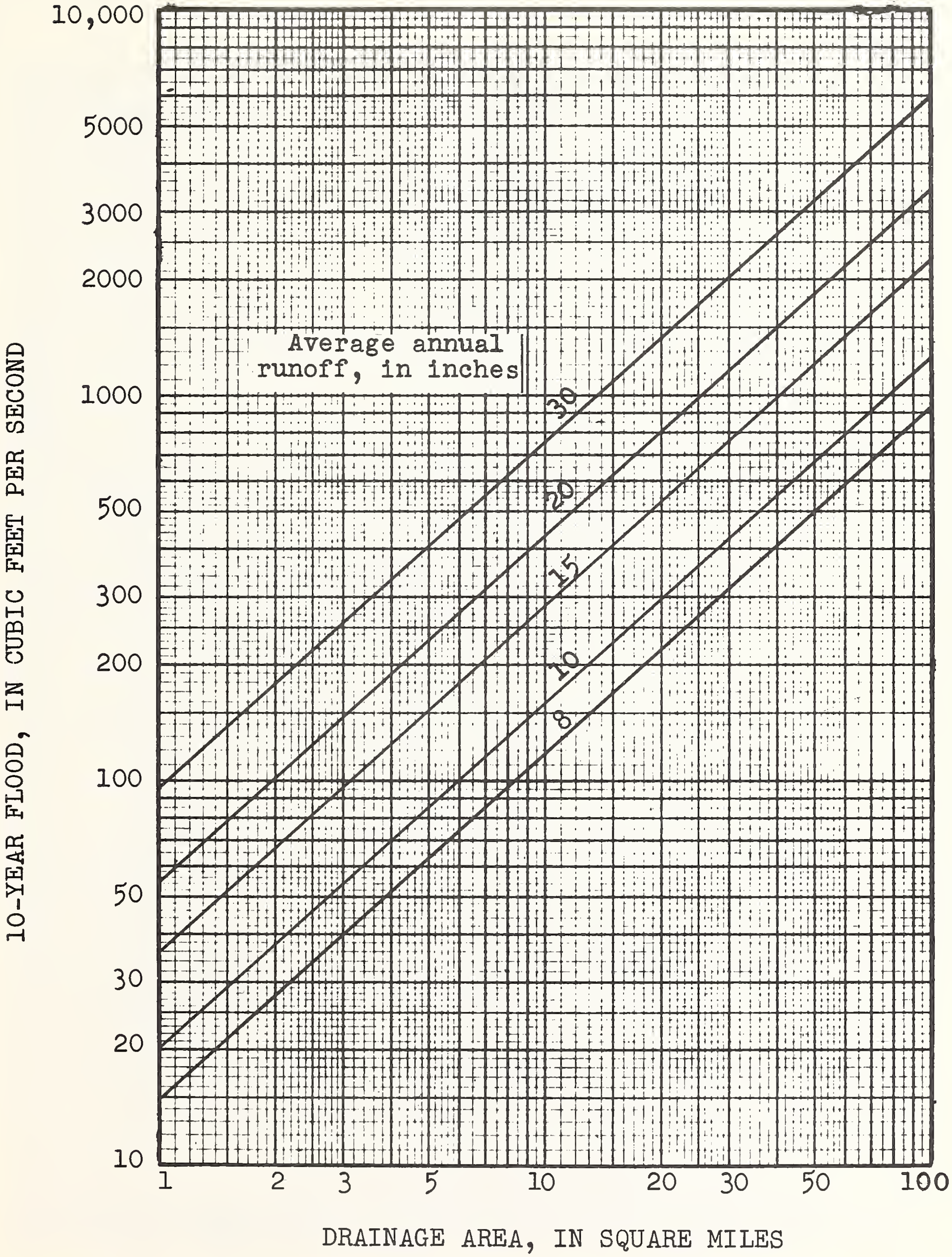

FIGURE 3.--Relation of 10-year flood to drainage area and average annual runoff in region A.

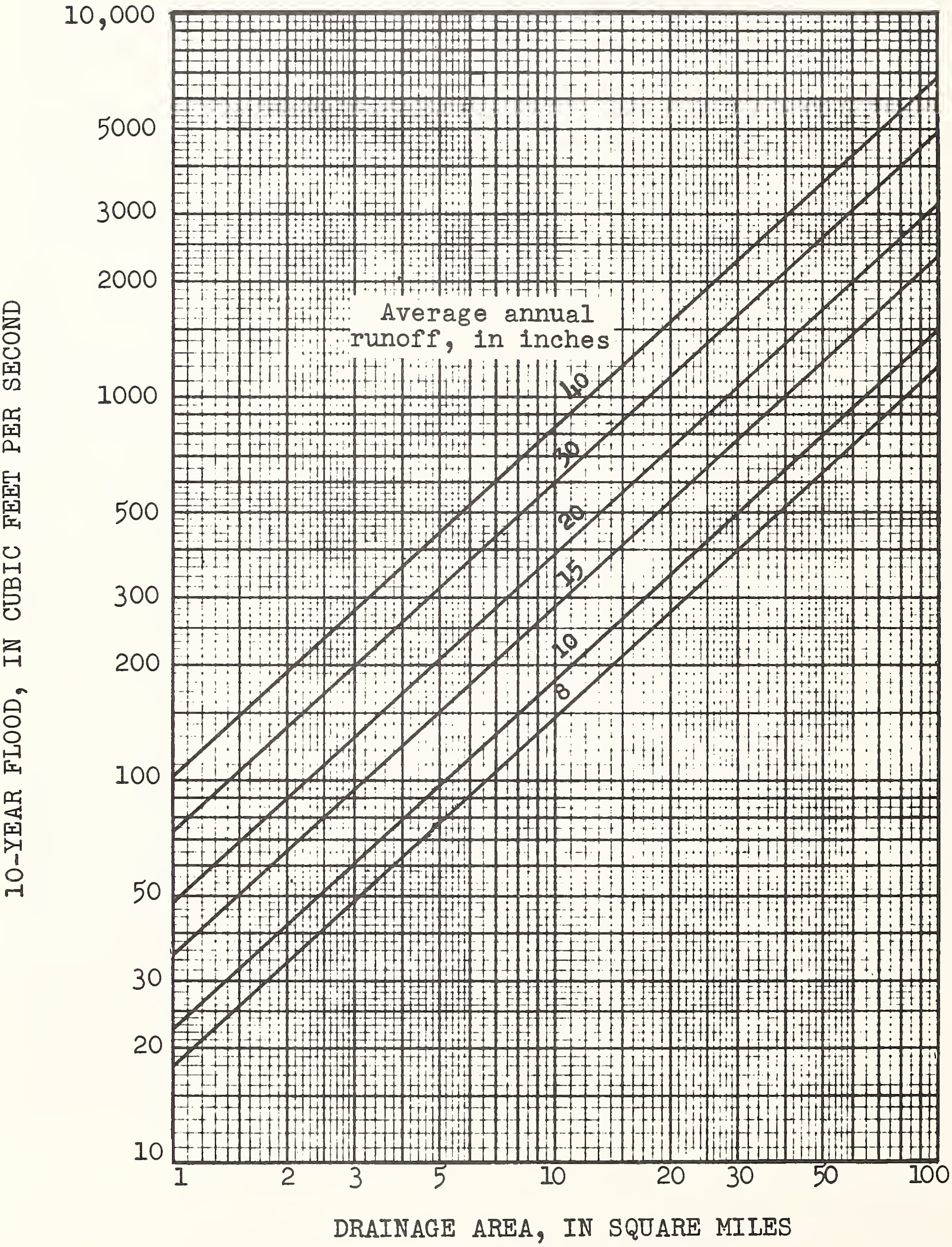

FIGURE 4.--Relation of 10-year flood to drainage area and average annual runoff in region C.

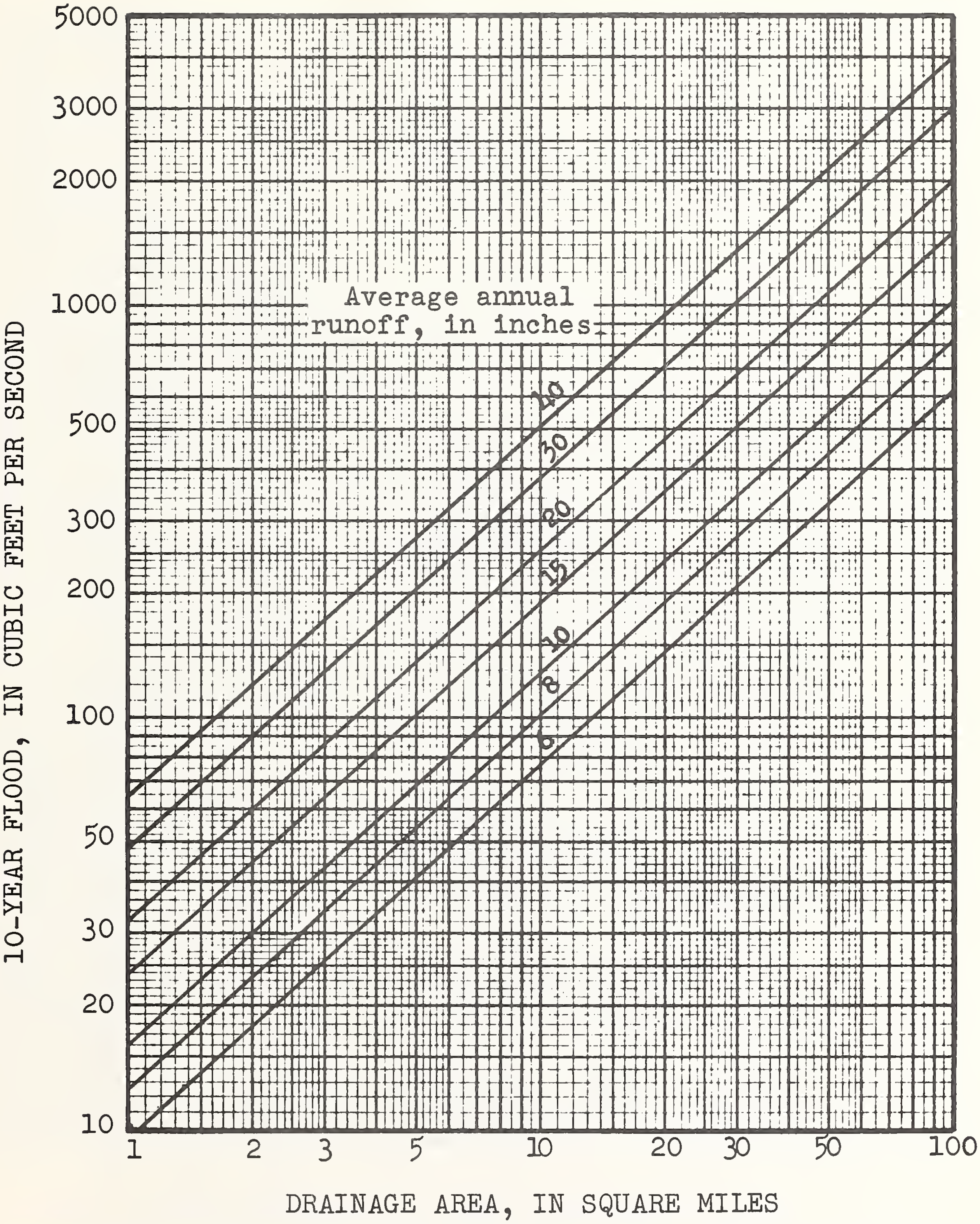

FIGURE 5.--Relation of 10-year flood to drainage area and average annual runoff in region D.

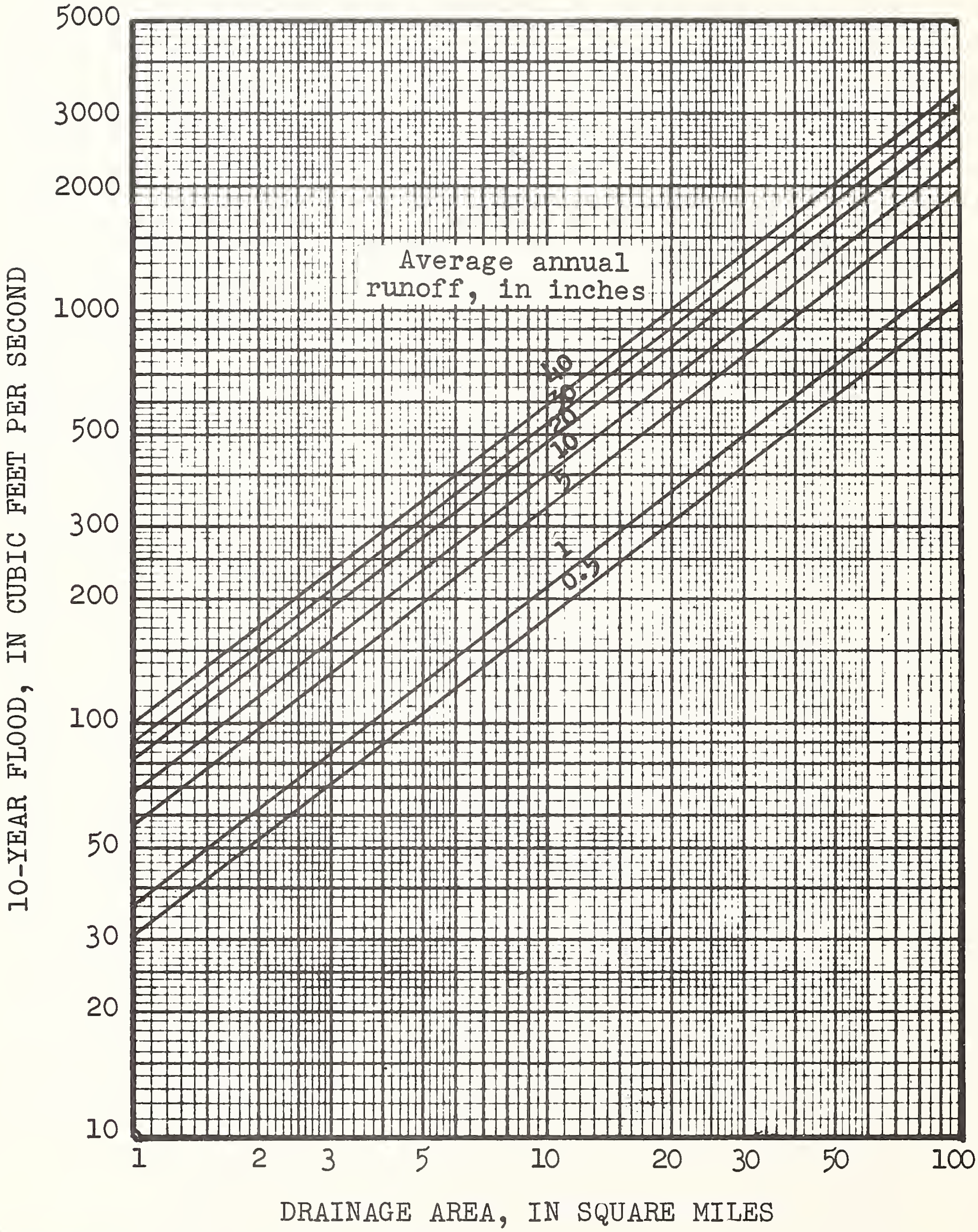

FIGURE 6. Relation of 10-year flood to drainage area and average annual runoff in regions E and F.

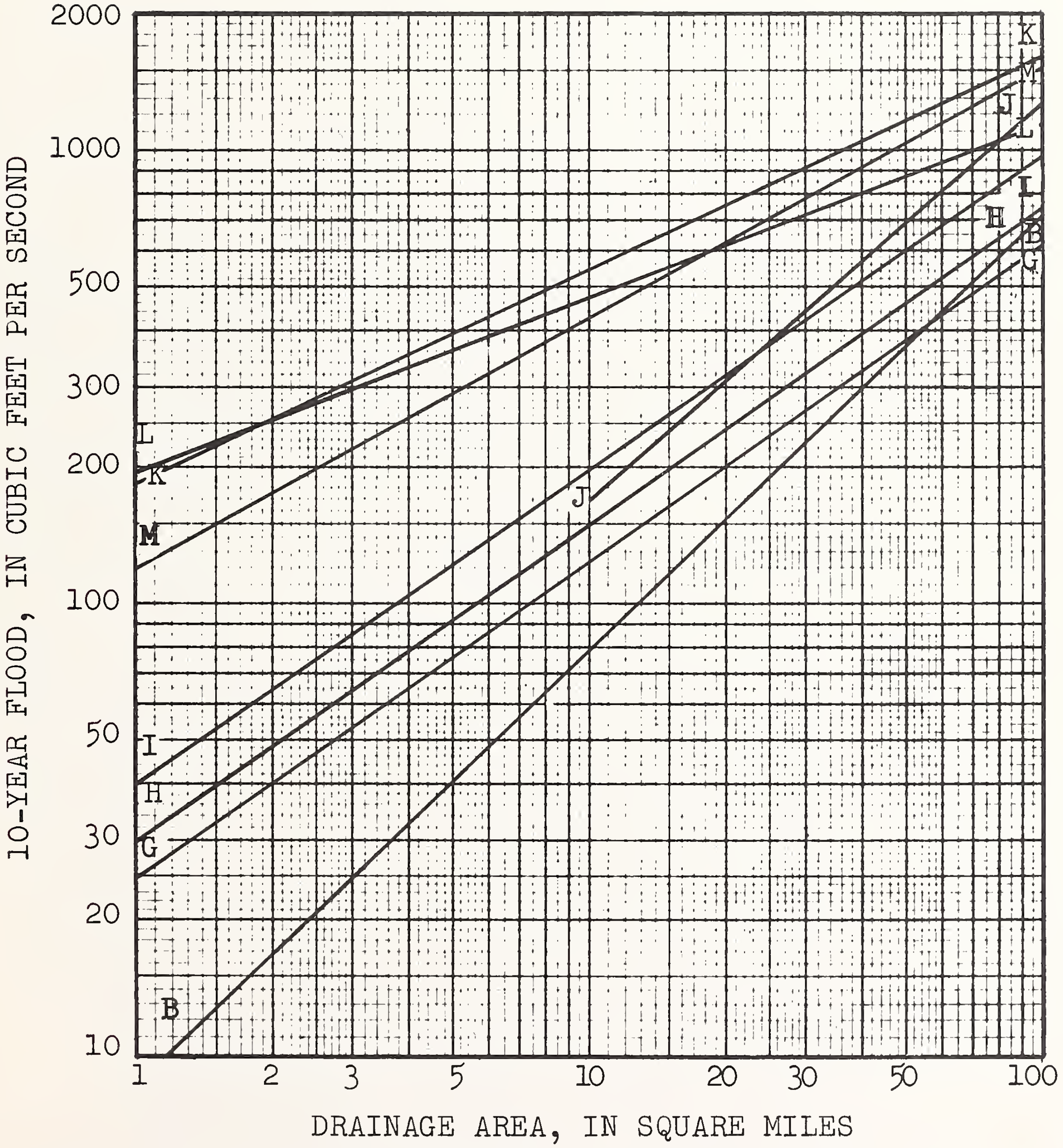

FIGURE 7.--Relation of 10-year flood to drainage area in regions B, G, H, I, J, K, L, and M.